Spring 5-27-2015

Solar Evaporative Fan Coil Unit

Kyle Kluever
Central Washington University, klueverk@cwu.edu

Samuel Budnick
Central Washington University, budnick5@cwu.edu

Jeremy Dickson
Central Washington University, dicksonje@cwu.edu

Follow this and additional works at: http://digitalcommons.cwu.edu/cwu_met

Part of the Mechanical Engineering Commons

Recommended Citation
http://digitalcommons.cwu.edu/cwu_met/3

This Book is brought to you for free and open access by the Student Scholarship and Creative Works at ScholarWorks@CWU. It has been accepted for inclusion in Mechanical Engineering and Technology Senior Projects by an authorized administrator of ScholarWorks@CWU.
Solar Evaporative Fan Coil Unit

Fan Coil Unit

Proposed By:

Kyle Kluever

Partners:

Samuel Budnick
Jeremy Dickson
Abstract

The purpose of any engineering project is to anticipate a need and meet that need through prediction analysis and design. Over 70% of the nation’s energy is consumed by building infrastructure such as HVAC systems, electrical, etc. HVAC systems use boilers to generate hot water or steam to heat buildings and evaporative chillers to provide air conditioning, much like the central plant on campus. The project included the construction of a solar collector that will heat water to 140F in order to run it through a heat exchanger that can have air passed over it. An evaporative chiller was also designed to harness the latent heat of vaporization to chill a heat exchanger that can then have water passed through it. The circulation pump and any temperature sensors will be powered by a photovoltaic array so that no electricity is needed to power the device. The air from the ducted fan can then be passed over this heat exchanger in order to generate hot air for a room, and the same for the cold air with cold water. Testing will consider input and output water temperature, as well as input and output air temperature in order to compare the changes and develop a value for efficiency. Initial testing has found that 140F heating water can provide enough load in a heat exchanger to provide 85F leaving air temperature. Water that has been cooled to 40F by the evaporative chiller can provide a leaving air temperature of 55F.
Table of Contents

Introduction .............................................................................................................................. 6
  Engineering Problem ......................................................................................................... 6
  Function Statement ......................................................................................................... 6
  Requirements ................................................................................................................... 6
  Engineering Merit ............................................................................................................. 6
  Scope of Effort .................................................................................................................. 6
  Success Criteria ................................................................................................................ 7

Methods ................................................................................................................................ 7
  Approach: Proposed Solution ............................................................................................ 7
    • Main Equation: .............................................................................................................. 7
  Description (picture, sketch, rendering) ............................................................................ 7
  Benchmark .......................................................................................................................... 10
  Performance Predictions ................................................................................................ 10
  Description of Analyses ................................................................................................... 10
  Scope of Testing and Evaluation ..................................................................................... 10

Analysis and Design .......................................................................................................... 11
  Approach: Proposed Sequence ......................................................................................... 11
  Design ................................................................................................................................ 11
  Calculated Parameters .................................................................................................... 12
  Device Shape .................................................................................................................... 12
  Device Assembly ............................................................................................................. 12
  Fabrication/manufacturing issues .................................................................................... 13
  Critical Failure Mode ....................................................................................................... 14

Construction ........................................................................................................................ 14
  Description ........................................................................................................................ 14
  Drawing Tree .................................................................................................................... 15
  Parts list and labels for most expensive items ................................................................. 16
  Manufacturing issues ....................................................................................................... 17

Testing Method .................................................................................................................. 19
  Introduction ...................................................................................................................... 19
  Method/Approach ............................................................................................................. 19
  Test Procedure ................................................................................................................ 19
  Deliverables ...................................................................................................................... 20
Appendix A

References

Acknowledgements

Conclusion

Budget/Schedule/Project Management

Proposed Budget

- Part suppliers, substantive costs and sequence or buying issues
- Labor
- Estimate total project cost
- Funding source(s)

Proposed schedule

- Define specific tasks, identify them, and assign times
- Specify deliverables, milestones
- Estimate total project time

Project Management

- Human Resources
- Physical Resources
- Soft Resources
- Financial Resources

Documentation

Design Evolution

Project Risk analysis

Successful

Next phase

Conclusion

Restate your design predicted performance vs actual performance, with respect to your requirements. Use bullets if appropriate.

Acknowledgements

References

Appendix A – Analyses

Heat Transfer Analysis [1] [6]

Hydronic Flow Rate [2]

Power Consumption Calculation [6]

Optimization (variable flow rate, fluid friction losses) [1]

Coefficient of Performance, SEER rating (to be completed with finalized data) [5]

Optimization (heat transfer analysis @ 80 CFM)

Optimization (heat transfer analysis @ 120 CFM)
Introduction

Engineering Problem

Climate control through HVAC applications is a leading consumer of power, both residentially and commercially. With limited energy resources, one must start to look to energy efficient products that can be incorporated with renewable resources to solve an issue with growing demand of power. The Solar Evaporative Fan Coil Unit is addressing this issue with the use of cooling and heating aspects that are less energy demanding.

Function Statement

A fan motor will drive recirculated air over cooled and/or heated coils within a containment structure, producing air at a comfortable output temperature.

The Solar Evaporative Fan Coil Unit must also be built to house the heat exchanger. This apparatus will be able to encapsulate the heat exchanger and allow access to the inside via a removable side panel. The airflow will be split at the fan motor, with a controllable amount of air flowing to both the evaporative unit and to the fan coil unit.

Requirements

The aspect of the system analyzed in this report must meet the following requirements:

- Must provide 20° F temperature drop in cooling cycle
- Fans must deliver a minimum flow rate of 100 CFM to both the evaporator and to the air handling unit
- Containment apparatus must be built to hold heat exchanging element with accessibility through removable side panel secured with screws.
- Apparatus must have a divergence method of splitting air flow

The fan will require an outside power supply and will be ducted into a return and supply cycle, meaning that it’s installation will be in-line.

Engineering Merit

The engineering merit of this aspect of the team’s project will be in the analysis of heat transfer between the water in the two separate temperature coils and the air being drawn through the air handler. There will also be merit in the optimization of air flow over said coils to have maximum heat transfer and efficient climate control. Incorporation of both the heating and cooling heat exchangers will offer a wider range of options for climate control in all applications.

Scope of Effort
Although part of a larger, more complex system, the scope of this aspect will be limited to the analysis and optimization of airflow over the cooling coils of the system. There is a heating aspect to the team’s system, but the scope has been limited extensively to the optimization of the cooling aspect.

**Success Criteria**

To be an effective addition to an existing HVAC system, the Solar Evaporative Fan Coil Unit will need to see a 20° F drop in temperature over these coils to cool the air (from 75° F entry air to 55° F exit air), and a 20° F raise in temperature if heating (from 65° F entry to 85° F exit). As discussed before, the heating aspect will not be analyzed through this report.

The optimization in the project will be determined by experimenting with insulation along the plumbing lines which contain the working fluid and determining any significant difference therein.

**Methods**

**Approach: Proposed Solution**

The main area of interest with the evaluation of this project will be in the heat transfer aspect. The Air Handling Unit Team needs to determine the heat load the unit can handle with regards to the rate of airflow. In preliminary calculations, they chose 100 CFM to start with, as this may be optimized through testing to get the maximum change in temperature.

- **Main Equation:**

The main equation required for determining the heat flow is as shown below:

\[
\dot{Q} = \dot{V}ol(\rho C_p)(\Delta T_{air,\text{out}})
\]

Where:
- \( \dot{V}ol \) is volume flow rate of air movement in CFM;
- \( \rho \) is density in lb\( m \) per cubic foot of air being moved
- \( C_p \) is specific heat capacity in BTU per lb\( m^* R \) of air
- \( \Delta T_{air,\text{out}} \) is difference in temperature of incoming/outgoing air over cooled coils

This will allow for finding the rate of heat loss to the cool coil, which can then be optimized via the volume flow rate to gain an optimum heat exchange rate.

**Description (picture, sketch, rendering)**
The evaporative cooler functions by blowing air over a heat exchanger with a working fluid dripping, usually water. This raises the humidity of the air passing over the coils (Figure 1). Due to the effect of theoretically constant enthalpy, the air which now has higher humidity will be cooler.

Moving the air over the heat exchanger assists in cooling the water within the unit via means of convection. This will allow for the heat exchanger to function as designed, and will allow for optimization on this aspect of the system through variations in the air flow rate.

Jeremy Dickson will be taking on the evaporative cooling aspect of the cooling cycle, and will be ducting his supply and return lines to the heat exchanger that will be placed within the fan coil unit. Sam Budnick will be compromising the solar heating aspect of the system, which will not be covered. For a better understanding of the system and how it will work together, see the following system schematic in Figure 2.
Figure 2 - System Schematic for Solar Evaporative Fan Coil Unit (sketched by Jeremy Dickson)
As seen above, the Air Handling Unit aspect of the overall project will supply cooled air to a room, with a fan splitting 100 CFM of air to both the evaporator and to the cooling coils. There is also a heating aspect to this system which will be incorporated into the Air Handling Unit. Kyle Kluever will not be analyzing the heating coil with regard to the air handling unit within the upcoming report.

Benchmark

Most of today’s air conditioning units use vapor-compression chilling cycles, which use electrical motors and refrigerants (commonly R-134a) to move heat from the incoming air to a heat reservoir via a reverse-Rankin cycle. Rather than using pressurized refrigerant, the Fan Coil Unit will utilize the large enthalpy of water to cool air using an evaporative cooling system. Otherwise known as a swamp cooler, the air handling unit team will drive room-temperature air saturated with water vapor over a heat exchanger, which will then be ducted into the air handling unit to reduce the electricity usage throughout the system, while still dropping the temperature of the air being ducted.

Performance Predictions

The Solar Evaporative Fan Coil Unit team is predicting a change in temperature of 20° F of air over the heat exchanging coil. Although this is a high expectation, the optimization will be in obtaining a starting ∆T, then getting that value as close as possible to 20° F. The aforementioned optimization includes fluctuating the hydronic flow rate of water through the system, changing the air flow over the heat exchanger, and also changing the air flow rate to both the evaporative cooler and to the air handling unit.

Description of Analyses

First, Kyle Kluever must analyze the amount of heat that is being given off by a set number of parameters. This analysis will involve researching the amount of energy a standard person and one standard computer give off into a room. After looking to online blogs and professional posts, a general value for one person and one small computer can be found.

After finding these values, Kyle Kluever will then be able to calculate the heat flow that must be absorbed into the cooled coils at the specified flow rate to not only meet this value of heat, but slightly surpass it to be able to cool the room effectively.

After finding this value, Kyle Kluever will be able to determine the rate at which cooled fluid must flow through the cooled coils to sustain this load. The value obtained will be correlated with Jeremy Dickson’s aspect of the cooling project and his aspect must be able to meet these energy absorption demands.

Scope of Testing and Evaluation

The testing will be relevant to the inlet and outlet temperature of the apparatus and how closely the temperatures correlate with the said 20° F drop in temperature. Optimization can be
performed via fluctuating the air mass flow rate over the coils and/or changing the rate at which the working fluid flows through the coil for maximum heat exchange.

**Analysis and Design**

**Approach: Proposed Sequence**

The air handling unit engineer will first find the heat loss rate necessary to cool 75°F air to a 55°F standard, based off of previously laid out standards.

After this, the team will be able to find the flow rate of cooling fluid necessary to do so based off of the amount of cooling data.

The team’s analyzed optimization will consist of variations of heat flow rate via experimentally changing both the hydronic flow rate and the air flow rate through the air handling unit and through the evaporator unit.

**Design**

The containment apparatus will house the heat exchanging element, and will have ducting going into and coming out of the unit. The fan motor will be attached to the ducting before entry into the apparatus. It will blow at 200 CFM, with 100 CFM going into the apparatus and the other 100 CFM going into the evaporative unit, which will then be exhausted into the outside air.

A box shaped device will be fine, as the fluid friction losses from such a design are calculable. A box shape is also easy to design and manufacture. The Air Handling Unit Team will have the side panel removable, with inlets cut into the side to accommodate the heat exchanger that is specified. This will allow for a tight fit, as the box is custom built for the heat exchanger. In a manufacturing sense, the design is simple. There are four bends on the main apparatus and one bend on each of the two required ducting connection pieces (See Appendix B for drawings and visuals). There will be spot welds on these pieces, and the gaps will be filled with caulk for insulation and producing a tight seal.

The ducting will be standard 6” aluminum accordion. There is a splitter with dampers to ensure that 100 CFM of air will reach the heat exchanger. The Air Handling Unit Team has also incorporated a motor speed controller (See appendix C), which will allow them to change the overall airflow, ensuring that the evaporator and the heat exchanger will each receive adequate circulation.
Calculated Parameters

Upon performing the initial calculation for the heat load removed (Appendix A, sheet 1), The Air Handling Unit Team found the amount of heat to be removed from the room at the outlined parameters to be 2140 BTU per hour [1] [2].

Looking to the text, they saw that the average male who is seated and doing very light work will emit 450 btuh of heat. Also, it was found that a small computer, such as a laptop produces roughly 145 W of waste heat, or 495 btuh [3]. Combined, the total heat load comes to roughly 950 btuh. Since the initial calculated parameter of heat load that could be removed is 2140 btuh, The Air Handling Unit Team can then move towards calculating the hydronic flow rate. This is the amount of fluid at a certain temperature that must be passed through a coil to produce a change in the air temperature that is passing over it. Looking to the appendix for the calculation, The Air Handling Unit Team found that a hydronic flow rate of 0.241 gallons per minute will accommodate this volume of heat flow out of the room (see appendix A, sheet 2) [2].

As seen in appendix A, sheet 8, the sheet metal must have a bend radius that is large enough to allow the material movement without “orange peeling”, or opening of the grain [4]. Upon analysis, it is found that the bend radius for a 90° bend on 20 gauge sheet metal is 0.063 in. This corresponds with the output value in Solidworks, which uses the minimum bend radius as a standard.

Device Shape

The device will be a box-shaped apparatus, containing two heat exchanging elements. The apparatus will feature inlet and outlet holes for both the air flow over the heat exchanger and the fluid flow throughout the unit.

The Air Handling Unit Team had also discussed adding a 1” layer of foam insulation around the air handling unit, then encasing it again with additional sheet metal. This was deemed unnecessary for their purposes, as this would be more applicable to a real-world scenario and not a testing application. Also, this would raise concern regarding access to the inner workings of the unit. A slight redesign would be in order, and if they wanted to take the idea to a marketing standpoint, The Air Handling Unit Team would need to reconsider that option. However, as a proof of concept, the uninsulated air handling unit will serve the purpose.

Device Assembly

The containment apparatus will have a three-sided structure made from 20 gauge steel sheet metal, and also incorporates a side panel which can be entirely removed from the unit. Since there are no structural requirements of the box from a loading standpoint, 20 gauge sheet metal is a viable option. It is also inexpensive, readily available and easier to work and bend. [4] The Air Handling Unit engineer plans to plasma cut the shapes out of stock 20 gauge sheet metal, so the fact that this is a thinner stock size makes for a cleaner cut as well as less warping from heat exposure both in welding and in plasma cutting.
The heat exchanger will be 12.5” x 14”, in a rectangular-shaped design (see Figures 3 & 4). There will be two panels that will cover the ends of the containment unit, each with a 6” hole cut into it for ducting. The fan will be connected to a splitting device, on which the Air Handling Unit team will mount butterfly dampers. This will allow the Air Handling Unit team to control the flow rate of air through both the evaporator and through the air-handling unit. All ducting will be standard 6” flexible aluminum.

For testing purposes, the evaporative cooler and the air handling unit will have separate air supplies to ensure proper control of flow rate as well as proper setup to measure temperatures and relative humidity depending on the needs of the testing engineer.

<table>
<thead>
<tr>
<th>Model</th>
<th>CFM</th>
<th>Ent-Water</th>
<th>500</th>
<th>600</th>
<th>700</th>
<th>800</th>
<th>900</th>
<th>1000</th>
<th>1916</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTL12 x 12</td>
<td></td>
<td>120</td>
<td>280</td>
<td>291</td>
<td>347</td>
<td>391</td>
<td>364</td>
<td>364</td>
<td></td>
</tr>
<tr>
<td>Based on</td>
<td>Load</td>
<td>160</td>
<td>330</td>
<td>359</td>
<td>427</td>
<td>479</td>
<td>479</td>
<td>479</td>
<td></td>
</tr>
<tr>
<td>RPM</td>
<td>0.49</td>
<td>180</td>
<td>438</td>
<td>486</td>
<td>539</td>
<td>564</td>
<td>564</td>
<td>600</td>
<td></td>
</tr>
</tbody>
</table>

Fabrication/manufacturing issues

The required tolerances will be 1/16” for the lengths and for the holes cut in the sheet metal. For the location of the holes to be drilled with the #31 drill, The Air Handling Unit engineer will require a tolerance of 1/32”. After speaking with Tedman Bramble and Matt Burvee regarding common practices for sheet metal tolerancing, there is no standard as far as fabrication goes. The containment apparatus will be attached with the ducting connection side panels via spot welds and caulking. After this has been completed, the removable side panel will be located and then drilled while on the unit. This will allow for tight control and easy location of the screw holes.
The entirety of the system will not be in motion, leading to kinematic considerations to be ignored. Although vibrations will be produced by the fan motor, they will be of insignificant magnitude. The system is designed to be semi-permanent and immobile, yet easy to install and maintain.

For the ergonomic aspect of this project, the human interaction with this system will be minimal. As with any maintenance, there will be some human interaction. This will be mitigated by the availability to access the coil through the removable side panel.

**Critical Failure Mode**

There are no load bearing aspects of the system. With that being said, the critical failure that could occur with this system would be failure in the heat exchanger itself and would present itself as a leak in the working fluid. This would be easily amended, yet would undoubtedly affect the performance of the system negatively if neglected due to pressure losses in the heat exchanger [5].

**Construction**

**Description**

20 gauge sheet metal (thickness of 0.0359”, Figure 5) will be used in the construction of this containment apparatus. This will allow the Air Handling Unit team to bend the sheet of metal in a Cornice brake to get the three-sided structure the device will need. There is also a need for lips on the two open sides of the containment apparatus. This will allow the air handling unit engineer to attach the removable side panel with screws for access to the heat exchanging elements. Next, the Air Handling Unit engineer will make a second sheet that is the size of the missing side and proceed to drill and tap holes into both the containment apparatus and the removable side panel.

Next, there will be two side panels with a 6” duct that will be applied to the open ends of the apparatus. This will be connected directly to the ducting via ducting that will end at the 6” fan motor (Figure 6), which will be installed directly to the unit. The Air Handling Unit engineer will be able to attach piece to the containment apparatus with tapped holes.

After this has been completed, the Air Handling Unit engineer will be able to install the heat exchanger. They will be placing the heat exchanger within the containment apparatus. This will allow for insulation as well as noise prevention within the unit. Next, the Air Handling Unit engineer will be cutting holes within the removable side panel to accommodate the inlet and outlet tubes for the heat exchanger. The tubes will have to be drained and disconnected from the transport sections of tubing to fit into the containment apparatus, but after initial installation,
there will not be a need to access the inner workings of the air handler. This allows for more of a semi-permanent installation of the heat exchanging coils.

**Drawing Tree**

Please see below the completed projected drawing tree for the team’s completed project. The final product will incorporate a solar collector for heating, an evaporator for cooling, and a fan coil unit to incorporate both designs.
Parts list and labels for most expensive items

**Figure 5 - 4’x10’ 20 Gauge Sheet metal price**

**Figure 6 - DC fan motor for use in system**

***For remainder of parts, consult Appendix C***
Manufacturing issues

There may be issues with using the equipment at CWU regarding the size of the air handling unit, namely using the Cornice Brake for the bending. If this is not a viable option, there will have to be sections cut from the raw stock of appropriate size with weldments to assemble the final product. There will have to be two cuts performed on the sheet metal, one for trimming and another for the removable side panel section. These cuts may be able to be performed on the plasma cutter, given that there will be an adequate support structure to hold up the overhanging material.

The first issue the Air Handling Unit engineer encountered was the warping of the sheet metal during cutting with the plasma cutter, as seen in Figure 7. Initially, this caused the head of the plasma cutter to become dislodged and stop cutting. The Air Handling Unit engineer was able to put compression on said sheet metal and mitigate the warping, allowing for a clean, even cut.

The next issue the Air Handling Unit engineer encountered was that the given dimensions of the heat exchanger did not take into account some of the tubes coming out of the manifold, as seen in figure 8. This problem affected the containment apparatus as well as the removable side panel. Fabrication modifications were made, resulting in the appropriate fit of the heat exchanger into the assembled device (see figure 9).
Figure 8 - Misconstrued dimensions of heat exchanger manifold

Figure 9 - Corrected construction for heat exchanger manifold
Another possible risk that was mitigated was the weight of the fan motor and ducting to disconnect the air inlet from the containment apparatus. This was solved using the addition of a brace, which would keep the assembly rigid if any excess forces were to be added to the ducting assembly.

Testing Method

Introduction

To test and determine the heat load that the air handling unit system can manage, the Air Handling Unit engineer must be able to measure the temperature of the outgoing fluids. In this case, the mediums through which the unit will be transferring energy are water and air. The water will be carrying the heat energy from the air via a heat exchanger. This water will then be taken back to the evaporative cooler for exhausting the contained energy. By measuring the temperature of the outgoing air with regards to the input air temperature, the Air Handling Unit engineer can get a heat flow rate, allowing them to understand and optimize the outcome.

The Air Handling Unit engineer is required to have a minimum drop of 15°F over the heat exchanger in the air handling unit, although a 20°F drop in temperature is optimal. There is also a need for a minimum of 100 CFM to both the air handler and to the evaporative cooler. The Air Handling Unit engineer will be interested in the inlet vs outlet temperature over the heat exchanger in this air handling unit. This will give a tangible heat load that is being extracted by the medium in the air handling unit.

The data will be taken by hand every 5-10 minutes during operation to give a time-lapse figure of how the system is performing. The measured data will include date, time, water temperature in and out of the air handling unit, the hydronic flow rate, the air temperature in and out of the air handling unit as well as this flow rate, and also notes on ambient conditions and other points of interest.

Method/Approach

In testing this cooling system, the device will be in an enclosed space (inside, Fluke Laboratory, Hogue Building) with a regulated HVAC system. The system will have power supply to the fan motor and controller, which the Air Handling Unit engineer will be varying for the optimization. Another need will be multimeters (supplied by Roger Beardsley) with thermocouples to measure the temperatures on the inlet and outlet ports for the air and water going into the air handling unit. The Air Handling Unit engineer will be using anemometers to measure the leaving air flow through the unit. The hydronic flow rate will be monitored and maintained through the digital readout on the pump itself, found to be at a constant 3 GPM.

Test Procedure
The ducting and construction of the systems complete, the Air Handling Unit team began to measure the temperature of the water entering and leaving both the air handling unit and the evaporative cooler. The optimization consisted of testing the inlet and outlet water temperatures between the evaporative cooler and the air handling unit with and without insulation on the lines. From this, the Air Handling Unit team was able to determine that insulating the lines provided better heat flow retention in the lines.

Deliverables

- **Main Testing**

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (Military)</th>
<th>Water Temp (°F)</th>
<th>Water Flow Rate (gpm)</th>
<th>Air Temp (°F)</th>
<th>Air Flow Rate (cfm)</th>
<th>Ambient Conditions</th>
<th>Notes</th>
<th>Delta T of air (°F)</th>
<th>Heat Flow (btu/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/24/2015</td>
<td>1600</td>
<td>59.4</td>
<td>58.4</td>
<td>3</td>
<td>64</td>
<td>61</td>
<td>114/70°F, mostly cloudy</td>
<td>Addressed Air in line issue; no heat gun</td>
<td>3</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1610</td>
<td>58.2</td>
<td>57.4</td>
<td>3</td>
<td>66</td>
<td>59.3</td>
<td>115/70°F inside air</td>
<td>Moved Inside; no heat gun</td>
<td>6.7</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1615</td>
<td>62</td>
<td>60.8</td>
<td>3</td>
<td>69.1</td>
<td>62.5</td>
<td>114.6/70°F inside air</td>
<td>no heat gun</td>
<td>6.6</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1618</td>
<td>64</td>
<td>62.8</td>
<td>3</td>
<td>69.4</td>
<td>64.4</td>
<td>115/70°F inside air</td>
<td>no heat gun</td>
<td>5</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1621</td>
<td>64.6</td>
<td>63.6</td>
<td>3</td>
<td>69.6</td>
<td>65.3</td>
<td>115/70°F inside air</td>
<td>no heat gun</td>
<td>4.3</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1630</td>
<td>64.4</td>
<td>63.2</td>
<td>3</td>
<td>70</td>
<td>65.6</td>
<td>115.4/70°F inside air</td>
<td>no heat gun</td>
<td>4.4</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1637</td>
<td>64.8</td>
<td>63.8</td>
<td>3</td>
<td>70.2</td>
<td>65.6</td>
<td>115/70°F inside air</td>
<td>no heat gun</td>
<td>4.6</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1639</td>
<td>65.4</td>
<td>64.6</td>
<td>3</td>
<td>79.9</td>
<td>66.1</td>
<td>114/70°F inside air</td>
<td>added heat gun</td>
<td>13.8</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1647</td>
<td>65.8</td>
<td>64.8</td>
<td>3</td>
<td>77.6</td>
<td>67</td>
<td>114.2/70°F inside air</td>
<td>added heat gun</td>
<td>10.6</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1702</td>
<td>66</td>
<td>65</td>
<td>3</td>
<td>88.5</td>
<td>67.1</td>
<td>116/70°F inside air</td>
<td>added heat gun</td>
<td>21.4</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1726</td>
<td>69.4</td>
<td>69.2</td>
<td>1</td>
<td>88.8</td>
<td>72.3</td>
<td>144/70°F inside air</td>
<td>added heat gun</td>
<td>16.5</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1733</td>
<td>70.8</td>
<td>70.2</td>
<td>3</td>
<td>89</td>
<td>73.5</td>
<td>143/70°F inside air</td>
<td>added heat gun</td>
<td>15.5</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1737</td>
<td>71.2</td>
<td>70.4</td>
<td>3</td>
<td>91.8</td>
<td>72.6</td>
<td>144.4/70°F inside air</td>
<td>added heat gun</td>
<td>19.2</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1741</td>
<td>71.2</td>
<td>70.6</td>
<td>3</td>
<td>92.2</td>
<td>72.6</td>
<td>140/70°F inside air</td>
<td>added heat gun</td>
<td>19.6</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1749</td>
<td>71.4</td>
<td>70.8</td>
<td>3</td>
<td>92.2</td>
<td>73</td>
<td>148.5/70°F inside air</td>
<td>added heat gun</td>
<td>19.2</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1752</td>
<td>71.4</td>
<td>70.8</td>
<td>3</td>
<td>92.6</td>
<td>72.6</td>
<td>138.5/70°F inside air</td>
<td>added heat gun</td>
<td>20</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1758</td>
<td>72</td>
<td>71.6</td>
<td>3</td>
<td>104.4</td>
<td>74.8</td>
<td>142/70°F inside air</td>
<td>added heat gun</td>
<td>29.6</td>
</tr>
</tbody>
</table>

*Figure 10 - Raw Data*

After analyzing the data obtained, the Air Handling Unit engineer found that there was an overall average heat load of 1841.9 btuh (figure 13) that was being removed from the room. If one looks at the points in which the system more closely resembles one with a larger load to be taken out (i.e. hot outside air being passed through the air handling unit and to a room), it is clear that the air handling unit is able to more effectively remove the heat load from the air (figure 11). This makes sense, as the working fluid (water) is relatively close to room temperature and will be less efficient at heat transfer as the temperature of the passing air comes near equilibrium with the working fluid in the system. When one simply looks at the points where a heat gun was used, the heat load taken from the system shoots to 2565.0 btuh, a point well above the proposed need. At the points where mild temperature equilibrium occurs, the heat load removed was 636.6 btuh, substantially lower overall.
Figure 11 - Heat flow removed by AHU based upon Delta T of air

Figure 12 - Heat flow removed by AHU based upon Air Flow Rate
The success criteria laid out was that a temperature drop of 20°F was to be obtained in the air handling unit, from 75°F down to 55°F. The average drop in temperature for the heat gun portion of data was 18.1°F (figure 13), close to the projected temperature drop. For the system with the standard removed heat load of 636.6 btuh and working with ambient temperatures, the Air Handling Unit team only saw a 5.1°F drop in temperature (figure 13). Their overall average temperature drop was 13.2°F. See figure 13 for additional information.

<table>
<thead>
<tr>
<th>Avg heat load w/ heat gun</th>
<th>Avg heat load w/o heat gun</th>
<th>Overall heat load average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2565.0</td>
<td>636.6</td>
<td>1841.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg inlet air temp</th>
<th>Avg outlet air temp</th>
<th>Avg Overall temp drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>82.1</td>
<td>68.9</td>
<td>13.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg temp drop w/ heat gun</th>
<th>Avg temp drop w/o heat gun</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.1</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Figure 13 - Averages of given raw data

- **Optimization**

The Air Handling Unit engineer also decided to look at how adding insulation to their working fluid transportation lines would affect the overall heat loss while in transit. The Air Handling Unit engineer conducted their testing with the insulation in place, then removed it after testing to obtain the corresponding data. Data was taken between the evaporative cooler output to the air handling unit input, and also from the air handling unit output to the evaporative cooler input (figure 14).

<table>
<thead>
<tr>
<th>Controlled Parameters</th>
<th>AHU inlet air temp = 80°F</th>
<th>Ambient Temp = 72°F</th>
<th>AHU air flow rate = 120 cfm</th>
<th>Hydronic flow rate = 1 gpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation? (Y/N)</td>
<td>Water Temp (°F) for Evap Cooler</td>
<td>Water Temp (°F) for AHU</td>
<td>Delta T: Evap Cooler out - AHU in (°F)</td>
<td>Average Temp Difference (°F)</td>
</tr>
<tr>
<td>Y</td>
<td>71.4</td>
<td>67.4</td>
<td>69.8</td>
<td>70.7</td>
</tr>
<tr>
<td>Y</td>
<td>71</td>
<td>66.8</td>
<td>69.4</td>
<td>70.3</td>
</tr>
<tr>
<td>Y</td>
<td>69.8</td>
<td>65.6</td>
<td>68.3</td>
<td>69.4</td>
</tr>
<tr>
<td>Y</td>
<td>69.2</td>
<td>64.8</td>
<td>67.7</td>
<td>68.9</td>
</tr>
<tr>
<td>N</td>
<td>69.2</td>
<td>66.4</td>
<td>67.5</td>
<td>68.7</td>
</tr>
<tr>
<td>N</td>
<td>69.2</td>
<td>66.2</td>
<td>67.8</td>
<td>68.9</td>
</tr>
<tr>
<td>N</td>
<td>69.4</td>
<td>66.4</td>
<td>68.2</td>
<td>69.3</td>
</tr>
<tr>
<td>N</td>
<td>69.6</td>
<td>66.2</td>
<td>68.4</td>
<td>69.2</td>
</tr>
</tbody>
</table>

Figure 14 - Raw Optimization Data
Budget/Schedule/Project Management

Proposed Budget

- **Part suppliers, substantive costs and sequence or buying issues**

  Most of the parts can be bought from Amazon.com and the internet. The shipping times for some of these parts may be a hassle, but after speaking with representatives it is possible to get expedited shipping.

  The first part of the project that needs to be started on would be the fabrication of the containment apparatus. This will not be difficult to manufacture, but it will be some of the most time consuming. The engineering team must cut the sheet metal to size, layout the pilot holes, drill them, bend the metal and then work on laying out and drilling matching holes for the removable side panel. The two panels connected to the ducting will be laid out and cut on a plasma table, which will only require minimal buffing to finish the parts. The team will then have to layout and drill those for manufacture with the containment apparatus. After this has been completed, the team will simply need to secure the ducting with caulk and fasteners to complete the project.

- **Labor**

  Since the Air Handling Unit team will be providing the labor, there will be no cost associated with this aspect. It will take roughly 8 hours to assemble the Air Handling Unit aspect of the part. At a base pay of $10/hour (slightly higher than the minimum wage in Washington State), this will come out to a total of $80.
• **Estimate total project cost**

The total projected cost is outlined to be **$352.84**. This cost does not include the price for labor, as the total cost for the project does not contain this value.

• **Funding source(s)**

Roger Beardsley, assistant professor for Engineering Technologies at Central Washington University, has expressed that he could use the air handling unit and evaporative cooler project as a lab for teaching heat transfer methods. For this, the air handling unit and evaporative cooling team will be completely funded through Central Washington University, and will grant the Engineering Department the project upon completion.

**Proposed schedule**

![Schedule Summary](image)

**Look to Appendix E for complete schedule**

• **Task outline and milestones**

The first quarter consisted of drafting the proposal, which meant getting the initial formatting satisfactory and getting the main aspects (introduction, analyses, methods, etc.) down on paper. Throughout the beginning of the second quarter, the team modified this document to a finalized product and began the build process. The assembly of the final product was completed at the end of this time frame. Through the third and final quarter, the engineers have evaluated the project through testing and displaying the results of said tests. Throughout the final quarter, the team presented the findings and turned in all applicable documents through the course of the entire project.

• **Estimate total project time**
The total time for this project was estimated to be around 161.5 hours. At the end of the project, one can see that the total time taken to complete the project was 135.1 hours, roughly 30 hours less than projected. The most time saved was in the document modification section, followed by the device construction section.

As you can see in the above figure (17), there are 8 separate categories that the engineers must complete: drafting of the initial proposal, modifying the analyses, modification of documents, finishing the proposal, part construction, assembly of final device, testing and evaluating said device, and delivering all documents and the project to the advisors.

Project Management

- **Human Resources**
  
  Human resources include engineering feedback from instructors including but not limited to Dr. Craig Johnson, Charles Pringle, and Roger Beardsley. Financing will fall on the Engineering Department at CWU, with Matt Burvee taking charge of ordering subsequent parts.

- **Physical Resources**
  
  The use of space at Central Washington University in the Hogue building will be essential. For storage, the Air Handling Unit team will be able to use the Senior Project room, in which they may be able to construct their project. Testing will have to incorporate a separate space with measurable dimensions.

  The Air Handling Unit team will also be using the machine shop and foundry heavily throughout their construction process, including but not limited to the Cornice Brake, CNC Mill, Lathes, Plasma Cutter, and other physical resources that the university may have to offer the Air Handling Unit team.

- **Soft Resources:**

  The Air Handling Unit team will be using Solidworks to assist with all aspects of their design throughout the design and building procedure. Upon commencement of testing, the Air Handling Unit team will start using Excel spreadsheets to assist with optimization of the system after the appropriate equations and have proven them effective.

- **Financial Resources**

  Financing will fall on the Engineering Department at CWU, with Matt Burvee taking charge of ordering subsequent parts. Upon completion, Roger Beardsley will receive the system as an educational demonstration tool.
**Documentation**

**Design Evolution**

Initially, the Air Handling Unit team knew that they would like to design a containment apparatus, and not much in that sense has changed. The means of cooling have changed, however. The Air Handling Unit team have moved from the idea of a vapor compression cycle using ammonia as the working fluid to an evaporative cooling system. There are many reasons that this jump was made, including safety and cost considerations.

Looking at what they needed to achieve for both the Environmental Innovation Challenge and for their graduation requirements, it was necessary to do a proof of concept rather than a full-function device. They decided that it would be beneficial to use one heat exchanger rather than two due to this fact. This allowed for the compaction of the dimensions on the containment apparatus while still satisfying their requirements. If they wanted to incorporate both of these systems into the same heat exchanger effectively later on, they would need to develop servos that were temperature regulated to change whether they were heating or cooling using the system. This is, of course, an expansion on the marketability of their finished product’s applicable use in industry, not in the educational setting in which it will be applied.

**Project Risk analysis**

The main risk of doing a project of this magnitude is the allotted time frame in which their team will have to complete the project. In a scheduling sense, it is imperative that they finish fabrication of the device and start testing before the end of March, 2015. There is also a fiscal aspect that they must consider, assuming they are not accepted into the Environmental Innovation Challenge this upcoming April. They will have to source the parts out or even change their design to fit a diminished budget. Luckily, they were able to gain assistance from CWU for covering the cost of the overall budget.

**Successful**

The engineers found that they were able to meet all of their requirements for device performance, and also finished in a timely manner being under budget. Overall, the engineers are pleased with the outcome of the overall project.

**Next phase**

The next phase would be to look more at the business aspect of this project to decide if it will be economically feasible. As for the project as it sits, the department will incorporate the device into different testing methods for educational purposes.

**Conclusion**
The Air Handling Unit of the Solar Evaporative Fan Coil Unit has been conceived, analyzed and designed to meet the design requirements presented. The Air Handling Unit team will work together to meet said requirements and construct a functioning device. Necessary parts and materials have been specified, sourced and budgeted for their attainment.

This project meets all requirements for a successful senior project, including:

1. Having exceptional merit in heat transfer and energy system areas
2. The size and cost of the system is within the parameters of their resources
3. Being in the utmost interest of the principal investigator

The Air Handling Unit team expects this device to function successfully by aforementioned requirements of heating and cooling a room. They will have the adequate heat flow to cool air for a set requirement of said heat.

Important analyses include heat load, hydronic flow rate, and power consumption calculations. These analyses contribute to the engineering merit of the Air Handling Unit project, and will assist in optimization of the device throughout testing.

**Design vs. actual performance**

The air handling unit engineer projected through analysis that a heat load of 2140 btuh could be achieved. At the point of maximum load on the system, it was found that a heat load of 2565.0 btuh could be achieved. This validates the overall effectiveness of the system.
Acknowledgements

The Air handling Unit team would like to thank Central Washington University for their commitment to higher education. They would also like to acknowledge CWU’s support of this project through use of equipment in the engineering department, including all applicable machines and software, as well as the use of the building space itself.

The team would like to extend thanks to their mentors, including but not limited to:

- Dr. Craig Johnson
- Charles Pringle
- Roger Beardsley
- Tedman Bramble
- Matt Burvee

The Air Handling Unit team would also like to thank MacDonald-Miller, University of Mechanical Contractors, Ellensburg Solar and Brad & Burke for their contributions to the project.
References


Appendix A – Analyses

Heat Transfer Analysis [1] [6]

Given: 0.5 m x 0.5 m enclosure, $T_{in}=75^\circ F=23.8^\circ C$, $T_{out}=55^\circ F=12.7^\circ C$, $V_{in}=100$ CFM = 47.210^3 m^3/s

Find: Heat loss needed to drop temperature

Assume: No frictional losses, 70% delin, 70% basic, ideal gas

Soln: $Q_{out}=V_{in}C_{p}(\frac{C_p}{C_p})\Delta T$

$\frac{C_p}{C_p}=2.7(14.7 psia)\frac{14.7 psia}{75+4597K}$

$T_{air}=0.0742 \text{ psia} / \text{ft}^2$

Table A-2EC

From Table A-2EC

$Q_{out}=(100 \text{ ft}^3/\text{min})[0.0742 \text{ psia} / \text{ft}^2][0.2404 \text{ BTU/ft}^3/\text{hr}][20\text{K}]$

$Q_{out}=2139.56 \text{ BTU/hr}=2140 \text{ BTU/hr}$
Given: $\Delta T = 20^\circ F$, $Q = 2140 \text{ Btu/h}$, $C = \text{hydronic heat transfer constant}$

Find: Hydronic Flow Rate ($V$)

Soln: 

\[ V = \frac{Q}{(C \Delta T)} = \frac{2140 \text{ Btu/h}}{500 \frac{\text{Btu}}{\text{gal} \cdot \text{h} \cdot ^\circ F}} \times (20^\circ F) \]

\[ V = 0.214 \text{ gal/min} \]
Given: Orion OD1238-24HB-VXC fan motor, V = 24 V, I = 1.7 A, Run time = 8 hrs/day

Find: Power consumed in 1 day of normal operation

Soln:

Power = (Voltage)(Current)

= (24 V)(1.7 A)

Power = 40.8 W

Power Consumption in avg. day:

\[ \frac{40.8 \text{ W} \times 8 \text{ hr}}{10000} \]

\[ = 0.326 \text{ KW-hr} \]
Minimum Bend Radius for Sheet Metal [4]

Given: 20 gauge Sheet Metal (t = 0.0359 in), Mild Steel
(AISI 1020), % Red. Area = 66%

Find: Minimum Bend Radius

Solution:

Machinery's Handbook
29th Edition
p. 1347

\[ R_{\text{min}} = T \left( \frac{50}{r} - 1 \right) \frac{3}{2} \text{Radius} \]
\[ r = \% \text{ reduction in area} \text{ (tensile test)} \]

\[ R_{\text{min}} = (0.0359 \times 50 \times \frac{30}{50} - 1) \]
\[ = 0.0017 \text{ in} > 0.06 \text{ in} \text{ (SolidWorks output)} \]

According to www.bjs-design.com, the American Iron and Steel Institute designates 0.063 in as minimum bend radii for AISI 1020.

\[ \therefore \text{ Use } R_{\text{min}} = 0.063 \text{ in} \]
Appendix B – Drawings

Assembly Drawing
Containment Structure
Appendix C – Parts List

Heat Exchanger 12x12”

4’x10’ 20 Gauge Sheet metal
AC fan motor for use in system

VenTech DF6 6" Duct Fan 240 CFM
by VenTech

List Price: $38.99
Price: $27.70 + $2.18 shipping
You Save: $11.29 (29%)

In Stock
Ships from and sold by Low_Baller.
Estimated Delivery Date: Feb. 3 - 6 when you choose Expedited at checkout.
- Air Flow: 240 CFM
- Power: 37 W * Input Voltage: 120v/60Hz *
- Dimension: 6" x 7" / Duct Size: 6"
- Max Temp: 140 Fahrenheit / Decibels: 68 +/- 1.5
- Package Includes: 1 - 6" Duct Fan / 1 Instructional Pamphlet

2 used from $17.98

Air Flow Splitter

Hydrofarm Y Connector, 6 x 6 x 6 in.
by Hydrofarm

Price: $21.09 + $5.49 shipping

In Stock.
Ships from and sold by brazilee.

Size: 6X6X6

10 x 6 x 6 in. 10 x 8 x 8 in. 12X10X10 Inch
4 x 4 x 4 in. 6 x 4 x 4 in. 6X6X6 8 x 6 x 6 in.
8X8X8

- Y Connector 6" x 6" x 6"

See more product details
Fan Speed Controller

VenTech VTSPEED Variable Dial Router Fan Speed Controller for Duct and Inline Fans
by VenTech

Price: $20.95 & FREE Shipping on orders over $35. Details

In Stock.
Sold by Low_Baller and Fulfilled by Amazon. Gift-wrap available.

Want it Tuesday, Dec. 27? Order within 17 hrs 20 mins and choose One-Day Shipping at checkout. Details

• Option - Variable Speed, Shut Down, Full Speed
• Current Capacity - 15 amps
• Replaceable Fuse
• Voltage Capacity - 120 AC
• Power Cord - 8' 3" / Double Insulated / UL Listed

See more product details

2 new from $19.75

Backdraft Damper

Fantech 9800004 RSK-6 Backdraft Damper, 6" Duct

List Price: $83.99
Price: $19.07 & FREE Shipping on orders over $35. Details
You Save: $64.92 (77%)

In Stock.
Sold by Professional Grade Products and Fulfilled by Amazon.

Want it Tuesday, Dec. 27? Order within 17 hrs 21 mins and choose One-Day Shipping at checkout. Details

13 new from $11.72

Specifications for this item

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brand Name</td>
<td>Fantech</td>
</tr>
<tr>
<td>EAN</td>
<td>0650737690501 , 0094700482198</td>
</tr>
<tr>
<td>Item Weight</td>
<td>3 pounds</td>
</tr>
<tr>
<td>Number of Items</td>
<td>1</td>
</tr>
<tr>
<td>Part Number</td>
<td>9800004</td>
</tr>
<tr>
<td>UNSPSC Code</td>
<td>40101600</td>
</tr>
<tr>
<td>UPC</td>
<td>650737690501 , 094700482198</td>
</tr>
</tbody>
</table>
Ducting

VenTech VTD625 6" inch Aluminum Duct for Ventilation Ducting

by VenTech

Price: $18.95 & FREE Shipping on orders over $35. Details

In Stock.
Sold by Low_Bailer and Fulfilled by Amazon. Gift-wrap available.

Want it Tuesday, Dec. 27 Order within 13 hrs 83 mins and choose One-Day Shipping at checkout. Details

- Applications: Bathroom, Green-House, Grow Room, HVAC and Tent
- Temperature Range: 0 to 185 F
- Strong Flexible Aluminum
- Easy to install
- 6 - Inch by 25 - Feet

See more product details

Fastener: Self-Tapping Screw

Steel Sheet Metal Screw, Zinc Plated, Hex Washer Head, Slotted Drive, Type AB, #6-20 Thread Size, 3/8" Length (Pack of 100)

Price: $3.71 & FREE Shipping on orders over $35. Details

Only 6 left in stock (more on the way).
Ships from and sold by Amazon.com. Gift-wrap available.

Want it Monday, Feb. 27 Order within 21 hrs 5 mins and choose One-Day Shipping at checkout. Details

Specifications for this item

<table>
<thead>
<tr>
<th>Brand Name</th>
<th>Small Parts</th>
<th>Size Name</th>
<th>#6-20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part Number</td>
<td>0609ABSW</td>
<td>Point Style</td>
<td>AB</td>
</tr>
<tr>
<td>Material Type</td>
<td>Steel</td>
<td>Thread Size</td>
<td>#6-20</td>
</tr>
<tr>
<td>Exterior Finish</td>
<td>Zinc Plating</td>
<td>Drive Style</td>
<td>Slotted</td>
</tr>
<tr>
<td>System of</td>
<td>Inch</td>
<td>Head Style</td>
<td>Hex Washer</td>
</tr>
<tr>
<td>Measurement</td>
<td></td>
<td>Number of</td>
<td>100</td>
</tr>
<tr>
<td>Color Name</td>
<td>zinc</td>
<td>items</td>
<td></td>
</tr>
<tr>
<td>Overall Length</td>
<td>3/8&quot; inches</td>
<td>UNSPSC Code</td>
<td>51101006</td>
</tr>
</tbody>
</table>
Fastener: Ducting Clamps

Milliard 6-Inch Ducting Clamps - 2 Pack
by Milliard

List Price: $43.99
Price: $8.99 & FREE Shipping on orders over $35. Details
You Save: $35.00 (36%)

Only 4 left in stock.
Sold by nilmee and Fulfilled by Amazon. Gift-wrap available.

Want it Tuesday, Dec. 27? Order within 13 hrs 56 mins and choose One-Day Shipping at checkout. Details

- Multi-purpose. Use them with any 6in. air duct system. Great for home & garden use.
- Adjustable and durable. Designed for use with MILLIARD Aluminum Foil Duct, the MILLIARD Inline Carbon Filter and MILLIARD 6in. Inline Blower Fan.
- Easily adjustable to secure tightly over 6in. fittings.
- Pack of two clamps

Caulking

Dap 18401 Crystal Clear Alex Plus Acrylic Latex Caulk Plus Silicone 10.1-Ounce
by DAP

Price: $5.76 & FREE Shipping on orders over $35. Details

In Stock.
Ships from and sold by Amazon.com. Gift-wrap available.

Want it Tuesday, Dec. 27? Order within 18 hrs 9 mins and choose One-Day Shipping at checkout. Details
Color: Crystal Clear

- Superior quality
- Moisture and mildew resistant caulk
- 35 year durability guarantee
- Paintable multi-purpose caulk for interior or exterior use
- Exceeds ASTM Spec. C-834-91
- See more product details
### Appendix D – Budget

<table>
<thead>
<tr>
<th>Part/Mat'l</th>
<th>Source</th>
<th>Description</th>
<th>Estimated Cost</th>
<th>Actual Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheet Metal</td>
<td>Metals Depot</td>
<td>20 ga 4x10'</td>
<td>$70.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>Heat Exchanger</td>
<td>amazon.com</td>
<td>12x12&quot; heat exchanger</td>
<td>$80.00</td>
<td>$69.00</td>
</tr>
</tbody>
</table>
| Fan Motor        | Allied Electronics | DC 24V 1.7 A  
120x120x38mm  
226 CFM          | $30.30         | $30.30      |
| Controller       | VenTech      | VTSPEED Variable Dial Router Fan Speed Controller | $20.95         | $20.95      |
| Ducting          | VenTech      | 6" Al Duct                                      | $18.95         | $16.10      |
| Dampers          | Fantech      | 6" Backdraft Damper                            | $38.14         | $25.40      |
|                  |              | 6" Butterfly Damper                            | $0.00          | $25.00      |
| Splitter         | Hydrofarm    | 6x6x6"                                          | $20.00         | $18.95      |
| Fastners         | Fastenal     | #6 Self-Tapping Sheet Metal Screws             | $5.00          | $0.00       |
|                  | Millliard    | 6" Ducting Clamps x 2                          | $17.98         | $9.99       |
| Caulking         | Dap          | Crystal Clear Latex Caulk plus Silicone         | $11.52         | $6.40       |
| SharkBite Fittings | amazon.com | UC139LFA, 3/4X1"                                | $0.00          | $7.80       |
| Hose Clamps      | amazon.com   | 5/16-7/8" 10 count                              | $0.00          | $3.85       |
| Ducting Collar   | TAACS        | 6" Start Collar                                | $0.00          | $11.99      |
| Adapters         | amazon.com   | 1" copper female                               | $0.00          | $3.57       |
| S&H              | N/A, Amazon Prime | Shipping/Handling  
|                  |              |                                                  | $40.00         | $0.00       |

**Total Cost** | **$352.84** | **$249.30**

***$0 in "actual cost" = donated; $0 in "estimated cost" = not originally accounted for***
## Appendix E – Schedule

### 459 - Senior Project Schedule

**PROJECT TITLE:** Solar Evaporative Fan Coil Unit  
**Investigated Aspect:** Air Handling Unit  
**Principal Investigator:** Kyle Kluever

<table>
<thead>
<tr>
<th>TASK ID</th>
<th>Description</th>
<th>Est. (hrs)</th>
<th>Actual (hrs)</th>
<th>% Comple</th>
<th>November</th>
<th>Dec</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
</table>

### Task 1: Proposal*

| 1.0 | Outline               | 2.0        | 1.5          | 100%     | November | Dec | January | February | March | April | May | June |
| 1.1 | Intro                 | 3.0        | 2.2          |          |          |     |         |          |       |       |     |      |
| 1.2 | Methods               | 4.0        | 3.7          |          |          |     |         |          |       |       |     |      |
| 1.3 | Analysis              | 3.0        | 3.6          |          |          |     |         |          |       |       |     |      |
| 1.4 | Discussion            | 2.0        | 1.6          |          |          |     |         |          |       |       |     |      |
| 1.5 | Parts and Budget      | 6.0        | 4.4          |          |          |     |         |          |       |       |     |      |
| 1.6 | Drawings              | 5.0        | 4.3          |          |          |     |         |          |       |       |     |      |
| 1.7 | Schedule              | 3.5        | 5.6          |          |          |     |         |          |       |       |     |      |
| 1.8 | Summary & Appx        | 1.0        | 0.5          |          |          |     |         |          |       |       |     |      |
|      | subtotal:             | 29.5       | 27.4         | 100.0%   |          |     |         |          |       |       |     |      |

### Task 2: Analyses

| 2.0 | Heat Trans => Geo     | 5.0        | 6.0          |          |          |     |         |          |       |       |     |      |
| 2.1 | Power Anal => Geo      | 2.0        | 1.5          |          |          |     |         |          |       |       |     |      |
| 2.2 | Tolerance => Geo       | 1.0        | 1.0          |          |          |     |         |          |       |       |     |      |
|      | subtotal:              | 8.0        | 8.5          | 100.0%   |          |     |         |          |       |       |     |      |

### Task 3: Documentation

| 3.0 | Pt1 Apparatus         | 1.0        | 1.0          |          |          |     |         |          |       |       |     |      |
| 3.1 | Pt2 Taper drawing     | 0.0        | 0.0          |          |          |     |         |          |       |       |     |      |
| 3.2 | Subassembly           | 2.0        | 4.0          |          |          |     |         |          |       |       |     |      |
| 3.3 | Pt3 duct diagram      | 4.0        | 0.2          |          |          |     |         |          |       |       |     |      |
| 3.4 | Heat Trans Check      | 6.0        | 2.2          |          |          |     |         |          |       |       |     |      |
| 3.5 | ANSYS14.5 Compl       | 4.0        | 1.0          |          |          |     |         |          |       |       |     |      |
| 3.6 | Make Object Files     | 2.0        | 2.2          |          |          |     |         |          |       |       |     |      |
|      | subtotal:              | 19.0       | 10.6         | 100.0%   |          |     |         |          |       |       |     |      |

### Task 4: Proposal Mods

<p>| 4.0 | Project Schedule      | 1.0        | 2.4          |          |          |     |         |          |       |       |     |      |
| 4.1 | Project Part Inv.     | 1.0        | 1.3          |          |          |     |         |          |       |       |     |      |
| 4.2 | Crit Des Review*      | 1.0        | 1.0          |          |          |     |         |          |       |       |     |      |
|      | subtotal:             | 3.0        | 4.7          | 100.0%   |          |     |         |          |       |       |     |      |</p>
<table>
<thead>
<tr>
<th>TASK ID</th>
<th>Description</th>
<th>Est. (hrs)</th>
<th>Actual (hrs)</th>
<th>% Comple</th>
<th>November</th>
<th>Dec</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Part Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5a get sheet metal</td>
<td>1.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5b make cuts</td>
<td>1.5</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5c bending</td>
<td>2.0</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5d spot welding</td>
<td>3.0</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5i installation</td>
<td>1.0</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5j update website</td>
<td>3.0</td>
<td>2.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5k Manufacture Plan*</td>
<td>2.0</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>subtotal:</td>
<td>13.5</td>
<td>9.5</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Device Construct</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6a assy of ducting</td>
<td>4.0</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6b assy of motor</td>
<td>1.5</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6c electrics w/ motor</td>
<td>4.0</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6d assy of connector</td>
<td>1.0</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6e take dev pictures</td>
<td>1.0</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6f update website</td>
<td>2.0</td>
<td>3.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>subtotal:</td>
<td>13.5</td>
<td>5.5</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Device Evaluation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7a list parameters</td>
<td>2.0</td>
<td>1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7b design test &amp; scope</td>
<td>3.0</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7c obtain resources</td>
<td>6.0</td>
<td>4.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7d make test sheets</td>
<td>4.0</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7e plan analyses</td>
<td>2.0</td>
<td>2.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7f instrument setup</td>
<td>2.0</td>
<td>4.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7g test plan</td>
<td>3.0</td>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7h perform evaluation</td>
<td>12.0</td>
<td>14.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7i take testing pics</td>
<td>1.0</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7j update website</td>
<td>2.0</td>
<td>5.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>subtotal:</td>
<td>37.0</td>
<td>36.2</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>495 deliverables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8a get report guide</td>
<td>1.0</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8b make rep outline</td>
<td>4.0</td>
<td>2.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8c write report</td>
<td>8.0</td>
<td>8.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8d make slide outline</td>
<td>4.0</td>
<td>2.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8e create presentation</td>
<td>5.0</td>
<td>6.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8f make CD deliveries</td>
<td>7.0</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8g write 495 CD parts</td>
<td>7.0</td>
<td>1.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8h update website</td>
<td>1.0</td>
<td>10.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8i project CD*</td>
<td>1.0</td>
<td>6.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>subtotal:</td>
<td>38.0</td>
<td>32.7</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Senior Project Schedule

**PROJECT TITLE:** Solar Evaporative Fan Coil Unit

**Investigated Aspect:** Air Handling Unit

**Principal Investigator:** Kyle Kluever

<table>
<thead>
<tr>
<th>TASK ID</th>
<th>Description</th>
<th>Est. (hrs)</th>
<th>Actual (hrs)</th>
<th>% Complete</th>
<th>November</th>
<th>December</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Draft Proposal</td>
<td>29.5</td>
<td>27.4</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Analyses Mod</td>
<td>8.0</td>
<td>8.5</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Document Mods</td>
<td>19.0</td>
<td>19.0</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Final Proposal</td>
<td>3.0</td>
<td>4.7</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Part Construction</td>
<td>13.5</td>
<td>13.5</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Device Construct</td>
<td>13.5</td>
<td>13.5</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Device Evaluation</td>
<td>37.0</td>
<td>36.2</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>495 Deliverables</td>
<td>38.0</td>
<td>32.7</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Hours</strong></td>
<td></td>
<td><strong>161.5</strong></td>
<td><strong>135.1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Deliverables
Appendix F - Expertise and Resources [2]

HVAC basics

It's important that young (and seasoned) engineers remain familiar with the principles and equations behind HVAC design and modeling software.

By Ben Biada, PE, LEED AP; and Carl C. Schatz, PE, LEED AP, Advanced Engineering Consultants, Columbus, Ohio

The design of HVAC systems is both an art and a science. While at one time it was dominated by hand calculations and "rules of thumb," that has given way to computer models and simulations. Although these new methods are at once useful and powerful, they have caused practitioners to lose some "feel" for the basics.

This article presents some of the most fundamental and useful equations used for HVAC design along with example calculations for air and water systems.

Approximating the central plant
A seasoned engineer can make good progress on conceptual designs using estimates and rules of thumb that can subsequently be refined by computer simulations as a building's design progresses. Waiting for an architect to develop the exact building footprint or draw wall sections to develop the computer model is not practical when mechanical rooms and shafts need to be roughed out and when the electrical engineer needs to plan service and work on one-line diagrams. Estimating the anticipated airflow and sizes of chiller and boiler plants needs to be accomplished early in the conceptual design phase in order to make progress as an integrated design team.

Early in the design, architects will want to know how large mechanical equipment rooms will be, where they should be located, and how big louvers will be, which can be done with some level of precision simply by taking into account the type of facility planned and the climate in which it will be located. Office occupancies are the easiest to estimate because we can assume 1 cfm of airflow over the gross square footage and be very close to the final design value.

This rule of thumb is quite old, and even though lighting wattage has decreased over the years and building envelopes have made great improvements, the increase in plug loads due to computers, monitors, and printers have left this approximation intact. From 1 cfm per gross sq ft, apply the rule of thumb of 1 ton of refrigeration for every 400 cfm of system airflow. Consider:

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>Density (lbm/ft³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.0862</td>
</tr>
<tr>
<td>30</td>
<td>0.0827</td>
</tr>
<tr>
<td>40</td>
<td>0.0791</td>
</tr>
<tr>
<td>50</td>
<td>0.0763</td>
</tr>
<tr>
<td>60</td>
<td>0.0732</td>
</tr>
<tr>
<td>70</td>
<td>0.0705</td>
</tr>
<tr>
<td>80</td>
<td>0.0684</td>
</tr>
<tr>
<td>90</td>
<td>0.0664</td>
</tr>
<tr>
<td>100</td>
<td>0.0650</td>
</tr>
<tr>
<td>110</td>
<td>0.0638</td>
</tr>
<tr>
<td>120</td>
<td>0.0627</td>
</tr>
<tr>
<td>130</td>
<td>0.0618</td>
</tr>
<tr>
<td>140</td>
<td>0.0610</td>
</tr>
<tr>
<td>150</td>
<td>0.0604</td>
</tr>
<tr>
<td>160</td>
<td>0.0608</td>
</tr>
<tr>
<td>170</td>
<td>0.0612</td>
</tr>
<tr>
<td>180</td>
<td>0.0616</td>
</tr>
<tr>
<td>190</td>
<td>0.0620</td>
</tr>
<tr>
<td>200</td>
<td>0.0624</td>
</tr>
<tr>
<td>210</td>
<td>0.0628</td>
</tr>
<tr>
<td>220</td>
<td>0.0632</td>
</tr>
<tr>
<td>230</td>
<td>0.0636</td>
</tr>
<tr>
<td>240</td>
<td>0.0640</td>
</tr>
<tr>
<td>250</td>
<td>0.0644</td>
</tr>
</tbody>
</table>

Table 3. Conversions for common engineering units

<table>
<thead>
<tr>
<th>Unit</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVAC</td>
<td>0.4426 BTU</td>
</tr>
<tr>
<td>EER</td>
<td>0.294 ECP</td>
</tr>
<tr>
<td>Units</td>
<td>0.254 kW</td>
</tr>
<tr>
<td>Gallon</td>
<td>0.133 cu ft</td>
</tr>
<tr>
<td>Flow</td>
<td>2.193 ft³/ft²</td>
</tr>
<tr>
<td>GPM</td>
<td>4.541 gal/min</td>
</tr>
<tr>
<td>Tons</td>
<td>7000 lb</td>
</tr>
<tr>
<td>MMBTU</td>
<td>1000000 BTU</td>
</tr>
</tbody>
</table>

Table 4. Selected constants

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific heat of water</td>
<td>0.0239 Btu/ft² °F</td>
</tr>
<tr>
<td>Density of water</td>
<td>8.33 gal/ft³</td>
</tr>
</tbody>
</table>

Consulting-Specifying Engineer • OCTOBER 2009
ering both increased outdoor ventilation rates and climate, it is often good to hedge this by going with 350 cfm per ton for the office buildings.

Not only are these types of approximations useful for preliminary estimations, but they can also be used to review the output of computer simulations. If the output significantly varies from what is estimated, the reviewer should dig deeper into the input data to uncover and resolve potential errors.

Estimating preliminary HVAC central plant capacities is just as simple for other occupancy types. For example, laboratories and healthcare occupancies are typically driven by air change rates with patient rooms at 6 air changes per hour (ACH), operating rooms at 15 to 25 ACH, and laboratory spaces at 8 to 12 ACH.

### Table 5. Hydronic heat transfer constant values for water/ethylene glycol solutions. The constant is equal to 500 for 100% water at standard conditions.

<table>
<thead>
<tr>
<th>Temperature (°F)</th>
<th>25</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethylene glycol</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>50</td>
<td>225</td>
<td>252</td>
<td>285</td>
<td>315</td>
<td>347</td>
<td>378</td>
<td>410</td>
<td>442</td>
<td>476</td>
</tr>
<tr>
<td>70</td>
<td>245</td>
<td>273</td>
<td>306</td>
<td>339</td>
<td>372</td>
<td>404</td>
<td>436</td>
<td>469</td>
<td>502</td>
</tr>
<tr>
<td>90</td>
<td>280</td>
<td>307</td>
<td>341</td>
<td>375</td>
<td>409</td>
<td>442</td>
<td>475</td>
<td>508</td>
<td>540</td>
</tr>
<tr>
<td>100</td>
<td>301</td>
<td>328</td>
<td>362</td>
<td>395</td>
<td>428</td>
<td>461</td>
<td>494</td>
<td>527</td>
<td>560</td>
</tr>
</tbody>
</table>

Right-sizing and sustainability

Building owners have been critical of HVAC designers for years, and rightly so, for the over-design of building services where it appears that rules of thumb were used and never refined with definitive calculations. But it should also be noted that blindly accepting the output of a computer simulation without gauging it against some simple "back of the envelope" calculations before proceeding with design is not wise.

Right-sizing (using design software and models) and sustainability go hand-in-hand, but approximations and rules of thumb are important tools for engineers to use in the early phases of a project. These rules of thumb also are useful to building

---

### Common rules of thumb

**HVAC hot water piping**
- Use 1.5 times # of tons for 100°F.
- Use 1.5 times # of tons for 120°F.
- Use 1.5 times # of tons for 140°F.
- Use 1.5 times # of tons for 160°F.

**HVAC chilled water**
- Use a temperature difference of 10 to 12°F.
- Use 1.5 times # of tons for 100°F.
- Use 1.5 times # of tons for 120°F.

**Ductwork**
- Use 80% of # of tons for 100°F.
- Use 90% of # of tons for 120°F.
- Use 100% of # of tons for 140°F.
- Use 110% of # of tons for 160°F.

**Supply Air**
- Use 1.2 times # of tons for 100°F.
- Use 1.4 times # of tons for 120°F.
- Use 1.6 times # of tons for 140°F.
- Use 1.8 times # of tons for 160°F.

**Heating and cooling load info**
- Heating: 36,000 Btu/h
- Cooling: 40,000 Btu/h

**Equipment info**
- Exchanger: 1,000 square feet and approx. 7,000 square feet for extension
- Condenser: 1,000 square feet for extension
- Chiller: 1,000 square feet for extension
- Distribution: 1,000 square feet for extension

---

### Typical office equipment loads

- Computer: 75 W
- Monitor: 75 W
- Desk lamp: 15 W
- Copy machine: 200 W (use 250 W)
- Phone: 15 W
- Riser: 100 W
- Elevator: 200 W
- Elevator: 300 W
- Lighting: 200 W
- HVAC: 120 W
- Electric space usage: 400 W

---

### Typical building construction U-values

- Wall: U-value 0.10 (R=10)
- Window: U-value 0.30 (R=3.33)
- Roof: U-value 0.60 (R=1.67)

---

Consulting: HVAC and Piping Engineers in California
owners and operators to check the work of their consultants as well as to assess the capacities of HVAC systems in their existing building stock.

Air and water basics

The HVAC design profession utilizes a variety of important equations to calculate the thermal content of moving streams of air and water, which are used to heat and cool buildings. For example, the sensible heat carried by an airstream, expressed in Btu per hour, is equal to 1.085 multiplied by the cfm and the temperature difference between the airstream's initial and final state (assuming standard conditions for the air). Many practitioners may not be aware of how the constant of 1.085 is derived and how to adjust its value for nonstandard conditions, such as when the system is operating at an altitude above sea level. The same holds for hydronic (water) systems, where the heat conveyed is equivalent to 500 multiplied by the gpm and temperature difference.

Sensible heat in an air stream

This equation is used to calculate the amount of heat that can be removed from a space with a certain amount of air at a certain AT.

Equation 3:

\[ Q = V \times (C \times AT) \]

Where:

- \( V \): Air flow rate (cfs)
- \( C \): Constant of 1.085
- \( AT \): Temperature difference (F)

Sample calculation:

Assume an air flow of 50,000 cfs with a \( AT \) of 20 F, the desired room temperature is 75 F, and with a supply air temperature of 55 F.

\[ Q = 50,000 \text{ cfs} \times 1.085 \times (20 \text{ F}) = 1,085,000 \text{ Btu/hr} \]

The air heat transfer constant 1.085 is contingent on the density of air, which can vary based on temperature and pressure. Table 2 provides the density of air at atmospheric pressure and varying temperatures, which can then be inserted into equation 4:

Equation 4:

\[ C = \rho \times C_p \times 60 \text{ min/hr} \]

Where:

- \( C \): Calculated air heat transfer constant (Btu/hr)
- \( \rho \): Fluid density (lbm/cu ft)
- \( C_p \): Specific heat (Btu/lbm x F)

More AERCO high-efficiency water heaters

AERCO SmartPlate

Specifications:

- 1 stage input up to 97 GPM with 1 stage
- 2 stage input option with 2 stages
- Plate and frame welded-vale design
- 0- or 3-way valve option
- Compact footprint 201/2W x 46h
- Stainless steel heat exchanger
- Potable water side surfaces are stainless steel copper or copper alloy
- Max. DWV pipe pressure drop is 8.25 GPD
- Max. boiler water pressure drop is 10 PSIG
- Max. DWV pressure & temp is 80 PSIG @ 180°F
- Max. boiler water pressure & temp is 150 PSIG @ 220°F

KC1000 Gas-Fired Water Heaters

- Market Proven for 22 Years
- 1 Million BTU/hr
- Hot Water
- 85% Efficiency
- 170°F Temperature Control
- 158°F Temperature Control
- 135°F Temperature Control
- 115°F Temperature Control
- Maximum Gas or Propane
- Optional Low Water Pressure Switch
- 6" Vent Size

WaterWizard Electrically Heated Heaters

- Self-Describing Rad Design
- 14°F Thermal Efficiency
- Insensitive to Thermal Shock
- No Trans or Tanks Required
- <1.5" Footprint
- Pneumatic or Electronic Controls
- Family of Steam-to-Water & Water-to-Water Units
- 20-Year Pressure Vessel Warranty

To learn more visit www.aerco.com/sp2

U-Tube Double Wall Heaters

- UL-listed Steam-to-Water & Water-to-Water Heaters
- <1°F Temperature Control
- <1.5" Footprint
- Pneumatic or Electronic Controls
- 20-Year Pressure Vessel Warranty

AERCO Heat You Can Bank On

Copyright © AERCO International, Inc.
Calculating hydronic flow rate

This equation is used to calculate the volumetric flow rate in gpm for a given amount of heat.

Equation 1:

\[ V = \frac{Q}{(C \times \Delta T)} \]

Where:

- \( V \): Volumetric flow rate (gpm)
- \( Q \): Heat flow rate (Btu/hr)
- \( C \): Hydraulic heat transfer constant: 600 (Btu/s min/gal x hr x F)
- \( \Delta T \): Difference in entering vs. leaving water temperature

While the hydraulic heat transfer constant \( C \) is typically assumed to be 600 in most conditions, it can vary depending on fluid density \( \rho \) and specific heat \( C_p \). Table 1 and Table 4 provide the density and specific heat of water at varying temperatures, which are then inserted in equation 2 to calculate the constant.

Equation 2:

\[ C = \rho \times C_p \times 60 \text{ (min/hr)} \times 0.134 \text{ (cu ft/gal)} \]

Where:

- \( C \): Calculated hydraulic heat transfer constant (Btu x min/gal x hr x F)

However, because ethylene glycol is frequently mixed with water to lower the freezing point of a fluid when it is used outdoors, the hydraulic heat transfer constant has to be determined based on the fraction of ethylene glycol in the solution. Table 2 provides the hydraulic heat transfer constant value for various ethylene glycol/water solutions.

Example: Assume a load of 750,000 Btu/hr and a \( \Delta T = 12 \text{ F} \) (Chilled water with no ethylene glycol).

\[ V = \frac{750,000 \text{ Btu/hr}}{(600 \text{ Btu/s min/gal x hr x F} \times 12 \text{ F})} \]

\[ V = 125 \text{ gpm} \]

Now, assume the same conditions, but this time assume the chilled water will be a mixture of 50% ethylene glycol.

\[ V = \frac{750,000 \text{ Btu/hr}}{(100 \text{ Btu/s min/gal x hr x F} \times 12 \text{ F})} \]

\[ V = 144 \text{ gpm} \]

Note: In this particular case, the ethylene glycol caused about a 15% increase in required gpm, which can have an impact on pump and pipe sizing. If increasing the flow is not desired, the fluid \( \Delta T \) or the amount of heat transfer can be varied to maintain the original gpm.

Stop overpaying to overheat your boiler water!

SmartPlate Water Heaters are designed to work with condensing boilers in low-temp systems.

**Advantages**

- 5°F Approach Temperature
  The plate heat exchanger design is efficient, the boiler water only has to be 5°F warmer than the desired DHW temperature.
  - Maximizes boiler efficiency
  - Reduces energy costs
  - Reduces scale build-up

Precise Temperature Control
  Precise temperature control is an important aspect of the boiler without relying on blending/mixing valves or storage tanks.
  - ±2°F under steady state
  - ±4°F under normal load changes
  - ±10°F wet load to full load

Fully-packaged Solutions
  Each unit ships fully assembled. This includes: control panel and sensors, potable water side circulator with clean out connections, DHW drain valve, as well as shut-off valves and inlet strainers on both the boiler water and DHW sides.
Determining total heat

This equation is used to calculate the amount of heat a piece of equipment is capable of removing from a space (also known as the total cooling capacity of a piece of equipment such as a rooftop unit, air handling unit, fan coil, etc.).

Equation 5:

\[ Q = C \times V \times \Delta h \]

Where:

- \( Q \) = Heat flow rate (Btu/hr)
- \( C \) = Heat transfer constant ((lbm x min) / (ft^2 x °F))
- \( V \) = Air flow rate (cfm)
- \( \Delta h \) = Difference in enthalpy of mixed air and supply air (Btu/lbm)

Again, the heat transfer constant is dependent on the density of air; pick the appropriate value from Table 2 and insert it into equation 5:

\[ C = \rho \times 60 \text{ min/hr} \]

Where:

- \( C \) = Heat transfer constant ((lbm x min) / (ft^2 x °F))
- \( \rho \) = Fluid density (lbm/ft^3)

Sample Calculation:

Assume the air flow is 42,000 cfm and \( \Delta h \) is 7.8 (i.e., the difference in enthalpy of mixed air and supply air):

\[ Q = 4.5 \text{ (lbm x min)/(ft}^2 \times °F) \times 42,000 \text{ cfm} \times 7.8 \text{ Btu/lbm} \]

\[ Q = 1,474 \text{ MBtu/hr} \]

Mixed air temperature

Here’s how to calculate the dry-bulb mixed air temperature based on outdoor and return air conditions.

Equation 6:

\[ T_{ma} = (\frac{C_{Fma} \times T_{oa}}{C_{Fma}}) + (\frac{C_{Fma} \times T_{ra}}{C_{Fma}}) \]

Where:

- \( T_{ma} \) = Mixed-air temperature (°F)
- \( C_{Fma} \) = Air flow rate of outside air (cfm)
- \( T_{oa} \) = Outside air temperature (°F)
- \( C_{Fma} \) = Air flow rate of return air (cfm)
- \( T_{ra} \) = Return air temperature (°F)
- \( C_{Fma} \) = Aggregate supply air flow rate (cfm)

An alternative calculation can be performed using Equation 7:

Equation 7:

\[ T_{ma} = (\text{Outside air fraction (°F)} \times T_{oa}) + (\text{Return air fraction (°F)} \times T_{ra}) \]

Sample calculation:

Assume an outside air temperature of 95 °F, a return-air temperature of 75 °F, and an aggregate supply air flow rate of 25,000 cfm with an outside-air fraction of 15%:

\[ T_{ma} = (25,000 \text{ cfm x 0.15 x 95 °F + 25,000 x 0.85 x 75 °F}) / 25,000 \text{ cfm} \]

\[ T_{ma} = (23,750 \text{ cfm x 95 °F + 21,250 cfm x 75 °F}) / 25,000 \text{ cfm} \]

\[ T_{ma} = 78.5 °F \]

Or, alternatively:

\[ T_{ma} = (0.15 x 95 °F + 0.85 x 75 °F) \]

\[ T_{ma} = 78 °F \]

Air change rate

Use this equation to calculate the air flow rate needed in cfm to meet a desired air change rate in a space.

Equation 8:

\[ C_{F_{ACH}} = \frac{L \times W \times H \times ACH}{60 \times \text{min/hr}} \]

Where:

- \( L \) = Length of room (ft)
- \( W \) = Width of room (ft)
- \( H \) = Height of room (ft)
- \( ACH \) = Desired or given air change rate (air changes/hr)

Sample calculation:

Given a 14-ft by 20 ft space with a height of 12 ft and a desired ACH of 8:

\[ C_{F_{ACH}} = 14 \text{-ft x 20-ft x 12-ft} \times 8 / 60 \]

\[ C_{F_{ACH}} = 460 \text{ cfm (approximately)} \]

The hydronic heat-transfer constant of 590 changes when a water/glycol solution is used as the heat transfer fluid. The sidebar equations show the derivations for these constants, and how they are dependent upon fluid density.

The sidebar also includes useful guidelines for designing air and water distribution systems. While it is beneficial to gain the fundamentals of HVAC design from classroom learning, these types of guidelines are developed from designers’ collective experience over the years and can help in quickly assimilating the skills necessary to get up to speed as a productive designer. Design firms often take pride in their design manuals and have slightly different guidelines based upon experience, and these most likely will change over time. For example, at one time high-pressure duct distribution systems were run at 3,000 to 4,000 fpm, which required large-horsepower fan systems and duct silencers. With modern energy codes, air distribution systems need to be operated at lower velocities, usually much less than 3,000 fpm, to comply with fan energy guidelines. It also should be noted that round duct systems usually can be operated at higher velocities than rectangular systems without noise being an issue.

While some of the more commonly used equations and guidelines are presented here, there are other sources of useful information such as the Mechanical Engineering Reference Manual and the ASHRAE Fundamentals Handbook. It is hoped that this information can be of use to new entrants to the HVAC design community as well the owners and operators of buildings that we design. If nothing else, it might get some discussion and debate going at the water cooler.

Blada is a project manager with Advanced Engineering Consultants. He has four years of experience designing mechanical systems for commercial and institutional facilities. Schultz is a vice president of Advanced Engineering Consultants and has 30 years of mechanical design experience.
## Appendix G – Evaluation Sheet

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Water Temp (°F)</th>
<th>Water Flow Rate (gpm)</th>
<th>Air Temp (°F)</th>
<th>Air Flow Rate (cfm)</th>
<th>Ambient Conditions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Appendix H – Testing Data

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Water Temp (°F) In</th>
<th>Water Flow Rate (gpm)</th>
<th>Water Temp (°F) Out</th>
<th>Water Flow Rate (gpm)</th>
<th>Air Temp (°F) In</th>
<th>Air Flow Rate (cfm)</th>
<th>Air Temp (°F) Out</th>
<th>Air Flow Rate (cfm)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/14</td>
<td>16:50</td>
<td>58.4</td>
<td>6.0</td>
<td>68.6</td>
<td>6.0</td>
<td>57.8</td>
<td>114.0</td>
<td>57.8</td>
<td>114.0</td>
<td>Moved Inside</td>
</tr>
<tr>
<td>4/14</td>
<td>17:00</td>
<td>58.2</td>
<td>6.0</td>
<td>68.6</td>
<td>6.0</td>
<td>57.8</td>
<td>114.0</td>
<td>57.8</td>
<td>114.0</td>
<td>Moved Inside</td>
</tr>
<tr>
<td>4/14</td>
<td>17:10</td>
<td>60.0</td>
<td>6.0</td>
<td>68.6</td>
<td>6.0</td>
<td>57.8</td>
<td>114.0</td>
<td>57.8</td>
<td>114.0</td>
<td>Moved Inside</td>
</tr>
<tr>
<td>4/14</td>
<td>17:20</td>
<td>60.0</td>
<td>6.0</td>
<td>68.6</td>
<td>6.0</td>
<td>57.8</td>
<td>114.0</td>
<td>57.8</td>
<td>114.0</td>
<td>Moved Inside</td>
</tr>
<tr>
<td>4/14</td>
<td>17:30</td>
<td>60.0</td>
<td>6.0</td>
<td>68.6</td>
<td>6.0</td>
<td>57.8</td>
<td>114.0</td>
<td>57.8</td>
<td>114.0</td>
<td>Moved Inside</td>
</tr>
<tr>
<td>4/14</td>
<td>17:40</td>
<td>60.0</td>
<td>6.0</td>
<td>68.6</td>
<td>6.0</td>
<td>57.8</td>
<td>114.0</td>
<td>57.8</td>
<td>114.0</td>
<td>Moved Inside</td>
</tr>
<tr>
<td>4/14</td>
<td>17:50</td>
<td>60.0</td>
<td>6.0</td>
<td>68.6</td>
<td>6.0</td>
<td>57.8</td>
<td>114.0</td>
<td>57.8</td>
<td>114.0</td>
<td>Moved Inside</td>
</tr>
<tr>
<td>4/14</td>
<td>18:00</td>
<td>60.0</td>
<td>6.0</td>
<td>68.6</td>
<td>6.0</td>
<td>57.8</td>
<td>114.0</td>
<td>57.8</td>
<td>114.0</td>
<td>Moved Inside</td>
</tr>
</tbody>
</table>

*Figure 18 - Test Data Sheet 1*
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Water Temp (°F)</th>
<th>Water Flow Rate (gpm)</th>
<th>Air Temp (°F)</th>
<th>Air Flow Rate (cfm)</th>
<th>Ambient Conditions</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/30</td>
<td>17:37</td>
<td>71.2</td>
<td>70.4</td>
<td>3</td>
<td>91.8</td>
<td>72.6</td>
<td>144.4</td>
</tr>
<tr>
<td>1</td>
<td>17:41</td>
<td>71.2</td>
<td>70.6</td>
<td>3</td>
<td>92.2</td>
<td>72.6</td>
<td>140.0</td>
</tr>
<tr>
<td>1</td>
<td>17:49</td>
<td>71.4</td>
<td>70.8</td>
<td>3</td>
<td>92.2</td>
<td>73.0</td>
<td>148.5</td>
</tr>
<tr>
<td>1</td>
<td>17:52</td>
<td>71.4</td>
<td>70.8</td>
<td>3</td>
<td>92.6</td>
<td>72.6</td>
<td>138.5</td>
</tr>
<tr>
<td>√</td>
<td>17:58</td>
<td>72</td>
<td>71.6</td>
<td>3</td>
<td>104.4</td>
<td>74.8</td>
<td>142.0</td>
</tr>
<tr>
<td>5/13</td>
<td>17:50</td>
<td>66.6</td>
<td>68.1</td>
<td>1</td>
<td>89.2</td>
<td>71.6</td>
<td>125 (rad)</td>
</tr>
<tr>
<td>17:57</td>
<td>68.1</td>
<td>69.8</td>
<td>1</td>
<td>96.1</td>
<td>74.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:02</td>
<td>69.5</td>
<td>71.5</td>
<td>1</td>
<td>80.8</td>
<td>76.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19:06</td>
<td>67.8</td>
<td>69.1</td>
<td>1</td>
<td>84.2</td>
<td>71.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:15</td>
<td>66.7</td>
<td>67.8</td>
<td>1</td>
<td>79.6</td>
<td>69.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:21</td>
<td>65.3</td>
<td>66.1</td>
<td>1</td>
<td>75.2</td>
<td>67.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18:28</td>
<td>65.8</td>
<td>66.3</td>
<td>1</td>
<td>71.1</td>
<td>67.5</td>
<td></td>
<td>Heat Run Off</td>
</tr>
<tr>
<td>Optimization</td>
<td>Water Flow Rate (gpm)</td>
<td>Condenser Water</td>
<td>Condenser Temp</td>
<td>Condenser Press</td>
<td>Yin</td>
<td>Yout</td>
<td>Yn</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------</td>
<td>----------------</td>
<td>----------------</td>
<td>----------------</td>
<td>-----</td>
<td>------</td>
<td>----</td>
</tr>
<tr>
<td>In</td>
<td>19</td>
<td>8.4</td>
<td>10</td>
<td>7.9</td>
<td>6.3</td>
<td>12</td>
<td>6.8</td>
</tr>
<tr>
<td>Out</td>
<td>7.0</td>
<td>6.6</td>
<td>6.6</td>
<td>6.7</td>
<td>6.4</td>
<td>6.8</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Figure 20 - Optimization Data
Appendix I – Testing Report

Introduction

To test and determine the heat load that the air handling unit system can manage, the Air Handling Unit engineer must be able to measure the temperature of the outgoing fluids. In this case, the mediums through which the unit will be transferring energy are water and air. The water will be carrying the heat energy from the air via a heat exchanger. This water will then be taken back to the evaporative cooler for exhausting the contained energy. By measuring the temperature of the outgoing air with regards to the input air temperature, the Air Handling Unit engineer can get a heat flow rate, allowing them to understand and optimize the outcome.

The Air Handling Unit engineer is required to have a minimum drop of 15°F over the heat exchanger in the air handling unit, although a 20°F drop in temperature is optimal. There is also a need for a minimum of 100 CFM to both the air handler and to the evaporative cooler. The Air Handling Unit engineer will be interested in the inlet vs outlet temperature over the heat exchanger in this air handling unit. This will give a tangible heat load that is being extracted by the medium in the air handling unit.

The data will be taken by hand every 5-10 minutes during operation to give a time-lapse figure of how the system is performing. The measured data will include date, time, water temperature in and out of the air handling unit, the hydronic flow rate, the air temperature in and out of the air handling unit as well as this flow rate, and also notes on ambient conditions and other points of interest.

Looking to the Gantt chart in Appendix E, one can see that the testing will be concluded by the middle of May, 2015, including the optimization of the system.

Method/Approach

In testing this cooling system, the device will be in an enclosed space (inside, Fluke Laboratory, Hogue Building) with a regulated HVAC system. The system will have power supply to the fan motor and controller, which the Air Handling Unit engineer will be varying for the optimization. Another need will be multimeters (supplied by Roger Beardsley) with thermocouples to measure the temperatures on the inlet and outlet ports for the air and water going into the air handling unit. The Air Handling Unit engineer will be using anemometers to measure the leaving air flow through the unit. The hydronic flow rate will be monitored and maintained through the digital readout on the pump itself, found to be at a constant 3 GPM.

There will be a heat gun pointed into the inlet of the airstream, to simulate warm environmental air, provided by the department. There is a thermocouple in the midst of this airstream to accurately measure the temperature of the air as it is entering the air handling unit. This air is then pushed over the cooled coils of the heat exchanger, where it is cooled. The Air Handling Unit engineer will be measuring the entering and exiting water temperature to obtain a value for the drop in temperature over these coils. The air then exits the unit where another thermocouple is placed to measure the exiting air temperature. As for the water circulation line, the Air Handling Unit team has replicated a closed-loop system using a hose fitting attached to a valve to...
be used for priming the line. There is also an air escape valve located at this point to take the air out of the system to more closely replicate a closed-loop system setup.

The data is collected by hand through reading the instrumentation and making observations. Data is collected at 5-10 minute intervals as the system is running. These points will then be plotted into Microsoft Excel to assist in determining a convergence point at which the system will have maximum effectiveness. The team has tried to keep air flow through the air handling unit a constant to try to vary the other factors, yet there are fluctuations in the actual air flow. This is being mitigated by taking an average CFM reading from the anemometer at the time of the data point collection. There are also thermal losses through the water line, which have been mitigated through the optimization of the system via insulation. The air handling unit itself may have thermal losses through the sheet metal, although such effects have been deemed trivial.

The data taken by hand will then be entered into Microsoft Excel and analyzed. The Air Handling Unit engineer will use the flow rate of air through the Air Handling Unit as well as the temperature difference obtained to calculate a heat flow rate that the device is removing from the air. This will be graphed to show the effects of heat flow verses both the air flow rate and the temperature drop. Data will be included that shows the device operating at normal room-temperature conditions as well as the device operating with a substantial heat load on it through the use of a heat gun. This will give the Air Handling Unit team accurate data that pertains to the capability of the system in a real-world scenario in which outside air is being cooled as it is ducted into a room.

Test Procedure

The Air Handling Unit engineer has tested vigorously on three separate dates, 4/24/2015, 5/13/2015 and 5/14/2015. In recording testing times alone, he has put in close to 3 hours. This does not include troubleshooting and setup times. All tests have been performed in the Fluke Lab in Hogue Technology Building, with only two data points having been taken outside. The testing was moved inside in an attempt to more readily control the atmospheric conditions for their testing purposes.

The ducting and construction of the systems complete, the Air Handling Unit team began to measure the temperature of the water entering and leaving both the air handling unit and the evaporative cooler. The optimization consisted of testing the inlet and outlet water temperatures between the evaporative cooler and the air handling unit with and without insulation on the lines. From this, the Air Handling Unit team was able to determine that insulating the lines provided better heat flow retention in the lines.

For testing purposes, the Air Handling Unit team set up independent air flow sources to assist in the control of fan speed and heat removal. The air handling unit had a heat gun pointed at the entrance with the fan on, leaving the control air flow to be 140 CFM as a base point of testing. The Air Handling Unit engineer also took data at higher and lower air flow rates to get a broad range of usable data at different conditions. He then began the cooling process. Jeremy will be monitoring the hydronic flow rate over the coils, which is controlled via a digital readout at the pump, and the Air Handling Unit team measured the input and output temperature and relative humidity of the air. The monitoring on the air handling unit had an anemometer on the output of
the system to measure the air flow. There were thermocouples placed on the inlet and outlet points of both the water source and air source to obtain accurate data.

There were really no adverse safety precautions that needed to be taken, but the Air Handling Unit team did however encounter issues with air getting into the lines for their plumbing. This was mitigated by the addition of an inlet valve to prime the system and an air-relief valve to get the majority of the air out of the line. After this was completed they were able to get all of the data when testing was performed.

Deliverables

- **Main Testing**

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (Military)</th>
<th>Water Temp (°F)</th>
<th>Water Flow Rate (gpm)</th>
<th>Air Temp (°F)</th>
<th>Air Flow Rate (cfm)</th>
<th>Ambient Conditions</th>
<th>Notes</th>
<th>Delta T of air (°F)</th>
<th>Heat Flow (btu/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/24/2015</td>
<td>1600</td>
<td>59.4</td>
<td>58.4</td>
<td>3</td>
<td>64</td>
<td>61</td>
<td>114.5°F, mostly cloudy</td>
<td>Added Air in line issue; no heat gun</td>
<td>3</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1610</td>
<td>58.2</td>
<td>57.4</td>
<td>3</td>
<td>66</td>
<td>59.3</td>
<td>115°F inside air</td>
<td>Moved Inside; no heat gun</td>
<td>6.7</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1615</td>
<td>62</td>
<td>60.8</td>
<td>3</td>
<td>69.1</td>
<td>62.5</td>
<td>114.6°F inside air</td>
<td>no heat gun</td>
<td>6.6</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1618</td>
<td>64</td>
<td>62.8</td>
<td>3</td>
<td>69.4</td>
<td>64.4</td>
<td>115°F inside air</td>
<td>no heat gun</td>
<td>5</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1621</td>
<td>64.6</td>
<td>63.6</td>
<td>3</td>
<td>69.6</td>
<td>65.3</td>
<td>115.7°F inside air</td>
<td>no heat gun</td>
<td>4.3</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1640</td>
<td>64.4</td>
<td>63.2</td>
<td>3</td>
<td>70</td>
<td>65.6</td>
<td>115.4°F inside air</td>
<td>no heat gun</td>
<td>4.4</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1637</td>
<td>64.8</td>
<td>63.8</td>
<td>3</td>
<td>70.2</td>
<td>65.6</td>
<td>115.5°F inside air</td>
<td>no heat gun</td>
<td>4.6</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1639</td>
<td>65.4</td>
<td>64.6</td>
<td>3</td>
<td>79.9</td>
<td>66.1</td>
<td>114.7°F inside air</td>
<td>added heat gun</td>
<td>13.8</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1647</td>
<td>65.8</td>
<td>64.8</td>
<td>3</td>
<td>77.6</td>
<td>67</td>
<td>114.2°F inside air</td>
<td>added heat gun</td>
<td>10.6</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1702</td>
<td>66</td>
<td>65</td>
<td>3</td>
<td>88.5</td>
<td>67.1</td>
<td>116.0°F inside air</td>
<td>added heat gun</td>
<td>21.4</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1726</td>
<td>69.4</td>
<td>69.2</td>
<td>1</td>
<td>88.8</td>
<td>72.3</td>
<td>144.7°F inside air</td>
<td>added heat gun</td>
<td>16.5</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1733</td>
<td>70.8</td>
<td>70.2</td>
<td>3</td>
<td>89</td>
<td>73.5</td>
<td>143.7°F inside air</td>
<td>added heat gun</td>
<td>15.5</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1737</td>
<td>71.2</td>
<td>70.4</td>
<td>3</td>
<td>91.8</td>
<td>72.6</td>
<td>144.4°F inside air</td>
<td>added heat gun</td>
<td>19.2</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1741</td>
<td>71.2</td>
<td>70.6</td>
<td>3</td>
<td>92.2</td>
<td>72.6</td>
<td>140.7°F inside air</td>
<td>added heat gun</td>
<td>19.6</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1749</td>
<td>71.4</td>
<td>70.8</td>
<td>3</td>
<td>92.2</td>
<td>73</td>
<td>148.5°F inside air</td>
<td>added heat gun</td>
<td>19.2</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1752</td>
<td>71.4</td>
<td>70.8</td>
<td>3</td>
<td>92.6</td>
<td>72.6</td>
<td>138.5°F inside air</td>
<td>added heat gun</td>
<td>20</td>
</tr>
<tr>
<td>4/24/2015</td>
<td>1758</td>
<td>72</td>
<td>71.6</td>
<td>3</td>
<td>104.4</td>
<td>74.8</td>
<td>142.7°F inside air</td>
<td>added heat gun</td>
<td>29.6</td>
</tr>
<tr>
<td>5/13/2015</td>
<td>1750</td>
<td>66.6</td>
<td>68.1</td>
<td>1</td>
<td>89.2</td>
<td>71.6</td>
<td>125.7°F inside air</td>
<td>added 2 nozzles to evaporative cooler; heat gun added</td>
<td>17.6</td>
</tr>
<tr>
<td>5/13/2015</td>
<td>1757</td>
<td>68.1</td>
<td>69.8</td>
<td>1</td>
<td>96.1</td>
<td>74.3</td>
<td>125.7°F inside air</td>
<td>added heat gun</td>
<td>21.8</td>
</tr>
<tr>
<td>5/13/2015</td>
<td>1802</td>
<td>69.5</td>
<td>71.5</td>
<td>1</td>
<td>100.8</td>
<td>76.4</td>
<td>125.7°F inside air</td>
<td>added heat gun</td>
<td>24.4</td>
</tr>
<tr>
<td>5/13/2015</td>
<td>1806</td>
<td>67.8</td>
<td>69.1</td>
<td>1</td>
<td>84.2</td>
<td>71.7</td>
<td>125.7°F inside air</td>
<td>added heat gun</td>
<td>12.5</td>
</tr>
<tr>
<td>5/13/2015</td>
<td>1815</td>
<td>66.7</td>
<td>67.8</td>
<td>1</td>
<td>79.6</td>
<td>69.9</td>
<td>125.7°F inside air</td>
<td>added heat gun</td>
<td>9.7</td>
</tr>
<tr>
<td>5/13/2015</td>
<td>1821</td>
<td>65.3</td>
<td>66.1</td>
<td>1</td>
<td>75.2</td>
<td>67.8</td>
<td>125.7°F inside air</td>
<td>no heat gun</td>
<td>7.4</td>
</tr>
<tr>
<td>5/13/2015</td>
<td>1828</td>
<td>65.8</td>
<td>66.3</td>
<td>1</td>
<td>71.1</td>
<td>67.5</td>
<td>125.7°F inside air</td>
<td>no heat gun</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Figure 21 - Raw Data

After analyzing the data obtained, the Air Handling Unit engineer found that there was an overall average heat load of 1841.9 btuh (figure 13) that was being removed from the room. If one looks at the points in which the system more closely resembles one with a larger load to be taken out (i.e. hot outside air being passed through the air handling unit and to a room), it is clear that the air handling unit is able to more effectively remove the heat load from the air (figure 11). This makes sense, as the working fluid (water) is relatively close to room temperature and will be less efficient at heat transfer as the temperature of the passing air comes near equilibrium with the working fluid in the system. When one simply looks at the points where a heat gun was used, the heat load taken from the system shoots to 2565.0 btuh, a point well above the proposed need. At the points where mild temperature equilibrium occurs, the heat load removed was 636.6 btuh, substantially lower overall.
Figure 22 - Heat flow removed by AHU based upon Delta T of air

Figure 23 - Heat flow removed by AHU based upon Air Flow Rate
As seen in the “Calculated Parameters” entry in the Analysis and Design Section, the projected heat load to be removed was 2140 btuh. The Air Handling Unit team were well within these parameters when their system was met with the higher entering temperature, but the system lost its effectiveness as ambient inlet temperatures were approached. If one looks at what the system would do under heavy loads, which is when it would be needed most, it is seen that the ability to dispose of excess heat is more than satisfactory (2410 btuh projected vs. 2565 btuh actual). It is also notable that as seen in figure 12, the heat flow that was able to be removed.

The success criteria laid out was that a temperature drop of 20°F was to be obtained in the air handling unit, from 75°F down to 55°F. The average drop in temperature for the heat gun portion of data was 18.1°F (figure 13), close to the projected temperature drop. For the system with the standard removed heat load of 636.6 btuh and working with ambient temperatures, the Air Handling Unit team only saw a 5.1°F drop in temperature (figure 13). Their overall average temperature drop was 13.2°F. See figure 13 for additional information.

<table>
<thead>
<tr>
<th>Avg heat load w/ heat gun</th>
<th>Avg heat load w/o heat gun</th>
<th>Overall heat load average</th>
</tr>
</thead>
<tbody>
<tr>
<td>2565.0</td>
<td>636.6</td>
<td>1841.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg inlet air temp</th>
<th>Avg outlet air temp</th>
<th>Avg Overall temp drop</th>
</tr>
</thead>
<tbody>
<tr>
<td>82.1</td>
<td>68.9</td>
<td>13.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg temp drop w/ heat gun</th>
<th>Avg temp drop w/o heat gun</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.1</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Figure 24 - Averages of given raw data

**Optimization**

The Air Handling Unit engineer also decided to look at how adding insulation to their working fluid transportation lines would affect the overall heat loss while in transit. The Air Handling Unit engineer conducted their testing with the insulation in place, then removed it after testing to obtain the corresponding data. Data was taken between the evaporative cooler output to the air handling unit input, and also from the air handling unit output to the evaporative cooler input (figure 14).
As seen in the above figures (15 & 16), the temperature differences recorded were higher in both transportation lines with the insulation on. This makes sense, as the ambient temperature in both scenarios was higher than the working fluid temperature in the lines, making heat transfer more likely to occur. It is also notable that less heat transfer was occurring in both scenarios upon leaving the air handling unit/entering the evaporative cooler. This is another instance in which the temperatures in the lines are closer to the ambient temperature, leading to a smaller overall change and, thus, less heat transfer.

**Conclusion**

The air handling unit engineer projected through analysis that a heat load of 2140 btuh could be achieved. At the point of maximum load on the system, it was found that a heat load of 2565.0 btuh could be achieved. This validates the overall effectiveness of the system.
Also, through optimization, the engineer found that insulating the lines allowed for heat retention and isolation in the plumbing lines transporting the working fluid.

Appendices

See Appendix H and Appendix G for information including evaluation sheet and testing data. See Appendix E for Gantt chart and scheduling information regarding testing.
Appendix J – Resume

Kyle Kluever
100 Sun Acres Road
Zillah, WA, 98953
(509) 949-1088
klueverkyle@gmail.com

Work Experience

Washington State Department of Transportation, June 2012 – September 2014

- June – September 2014; Engineering internship, worked as an inspector on cable net slope protection on Snoqualmie Pass, WA. Duties included material tracking, strength of material testing, supervision of installation, and coordination with companies regarding payment. Also performed work on avalanche-arrest snow nets regarding tolerancing criteria and testing.

- June – September 2013; Engineering internship, worked as an inspector on avalanche-arrest snow nets. These nets are the first of their kind in the United States. Learned management, employer-contractor communication and strength of materials testing skills.

- June – September 2012; Engineering internship, worked on survey crew on the I-90 – Snoqualmie Pass Project. Gained valuable leadership experience and skills related to working with a team, as well as basic understanding of concepts in surveying and computer aided design.

Education

Zillah High School – Zillah, WA
- Graduated with Honors, 5th in class, top 10% in WA

Yakima Valley Community College – Yakima, WA
- Completed Associate's Degree with High Honors, 3.95 GPA

Central Washington University
- Will be graduating in June, 2015 with a BS in Mechanical Engineering Technology

Achievements/Extracurricular Activities

- President's list at Yakima Valley Community College – Winter 2011-12, Spring 2012 and Fall 2012
- Dean's list at Central Washington University – Winter 2012-13, Spring 2013, Fall 2013, Winter 2013-14, Spring 2014
- FIRST Robotics Competition volunteer – Spring 2013
- ASME member – Winter 2012-13 to present
- SME member – Vice President, Fall 2014 – Spring 2015; Secretary, Winter 2012-13 to Spring 2014.
Skills

Engineering concepts, including strength of materials (class & employment experience), technical dynamics, thermodynamics, fluid dynamics, analysis of energy systems, finite element analysis, Nationally Certified in Solidworks, AutoCAD experience, CNC Programming, MasterCAM, electrical circuits, hydraulics and pneumatics, metallurgy, composites and ceramics, basic and advanced machining.

Excellent at interdisciplinary communication as well as technical writing skills. Am able to work efficiently in a team or group setting. Effective time management and problem-solving skills regarding individual projects. Also have management experience on a small scale and can coordinate well between trades and disciplines.

Honest, flexible and hardworking. On time, on point, and ready to accept any challenge.

References

<table>
<thead>
<tr>
<th>Name</th>
<th>Number</th>
<th>Position</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Will Smith, P.E.</td>
<td>(509) 577-1844</td>
<td>Project Engineer</td>
<td>WSDOT Headquarters, Union Gap, WA</td>
</tr>
<tr>
<td>Bobby E. Hooker, P.E.</td>
<td>(509) 577-1842</td>
<td>Assistant Project Engineer</td>
<td>WSDOT Headquarters, Union Gap, WA</td>
</tr>
<tr>
<td>Roger Beardsley</td>
<td>(509) 963-1596</td>
<td>Assistant Professor</td>
<td>Central Washington University</td>
</tr>
</tbody>
</table>